NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3698

PRELIMINARY INVESTIGATION OF SELF-EXCITED VIBRATIONS OF SINGLE PLANING SURFACES

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PRELIMINARY INVESTIGATION OF SELF-EXCITED VIBRATIONS OF SINGLE PLANING SURFACES[1]

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SUMMARY

A preliminary investigation was made of self-excited vibrations of single planing surfaces. A self-excited oscillation requiring freedom in rise but not in trim occurred with high aspect ratio (order of 10) of the wetted portion. This vibration could be controlled most successfully by methods (such as the use of dead rise) which limited the wetted aspect ratio.

INTRODUCTION

A tendency for single flat planing surfaces to vibrate has been observed during force tests (ref. 1). The motion occurred at small wetted lengths and appeared to be essentially an oscillation in trim or rise or a combination of these. This type of vibration has not been encountered on seaplane hulls, perhaps because these hulls generally do not have flat bottoms or because the hull structures are very rigid. This vibration, nevertheless, is significant for hydro-skis, which may be flat-bottomed near the trailing edge and have an inherently less rigid structure than the seaplane hull. There have been instances in which severe vibrations of hydro-skis have occurred and caused structural damage to the airplane and discomfort to the pilot.

Because the vibration of planing surfaces has become a practical problem, a preliminary investigation of the vibration of single planing surfaces has been made. Various types of planing surfaces were tested on a practical hydro-ski configuration, the effects of varying some of the structural and geometric properties of the configuration were sought, and tests were made to determine the degrees of freedom requisite for the vibration to occur.

[1]Supersedes recently declassified NACA Research Memorandum L55J27 by Elmo J. Mottard, 1955.

MODEL AND APPARATUS

The basic hydro-ski model and towing apparatus are shown in figures 1 and 2. The ski was made of spruce in the shape of a rectangular board and was attached to a massive I-beam by means of pivots so as to permit freedom in bending. The mass of the towing gear (exclusive of the counterweights) was 200 pounds, which was sufficiently large to eliminate vertical translation of the ski support at the vibratory frequencies encountered. The distance l from the rear pivot to the trailing edge of the ski was 17 inches and the thickness t was 0.94 inch. The mechanical properties of the ski are given in table I. An accelerometer, used merely as a vibration detector, was fastened to the hydro-ski midway between the pivots.

In order to determine the effects of varying some of the design characteristics, the basic hydro-ski (fig. 3(a)) was modified as follows:

Angles of dead rise of 10° and 20° (figs. 3(b) and 3(c)) were provided by fastening blocks of the proper shape to the trailing edge. The blocks were short and light in weight so that the mechanical properties of the hydro-ski were not appreciably altered.

Transverse circular-arc curvatures having radii of 9.14 inches and 4.86 inches (figs. 3(d) and 3(e)) were similarly provided. The cylindrical surfaces were designed to circumscribe the prismatic surfaces of figures 3(b) and 3(c). The alteration did not appreciably affect the mechanical properties of the hydro-ski.

The trailing edge was made pointed in plan form. A single 60° point (fig. 3(f)), two points (fig. 3(g)) designed to give the same variation of wetted area with draft as the single point, and five points of 60° (fig. 3(h)) were tried. The mechanical properties were not appreciably affected by these changes.

The thickness t (fig. 1) was varied from 0.5 inch to 1.5 inches; the resulting variations in the mechanical properties are shown in table I(a).

The overhang l (fig. 1) was decreased from 17 inches to 1 inch in four stages; the effects on the mechanical properties are shown in table I(b).

In order to determine the effect of eliminating the change in trim of the planing surface, the arrangement shown in figure 4 was used. The small planing surface located midway between the fixed pivots of the simple beam is effectively constrained to move in the vertical direction when the beam vibrates with small amplitude in the first mode. Two accelerometers were used in order to facilitate discrimination between the first mode and higher modes. A spray shield was provided to prevent spray from hitting the beam.

The Langley tank no. 1, in which the tests were made, is described in reference 2. The water in the tank was 12 feet deep during the tests.

PROCEDURE

The load and trim were held constant during the test run. Because the trim was set and measured at zero load, the trim of the trailing edge of the hydro-ski when under load was different from the measured trim. The trim of the trailing edge may be computed, if desired, by the use of table I. The model was accelerated at a constant rate of 1.5 feet per second per second up to a maximum speed of 80 feet per second. The speed and accelerometer output were recorded, and the speed at which vibration started was obtained from the record, where the start of the self-excited vibration was evidenced by a sudden increase in the accelerometer output (fig. 5). As an aid in distinguishing modes and visualizing the vibration, motion pictures were made in which an illusion of slowing down the oscillations was obtained by setting the camera speed (in frames per second) slightly slower than the vibration frequency. A similar technique was used with a flashing lamp for direct observation.

In order to protect the towing gear from the effects of salt spray, shields were provided. Check runs made without these shields indicated that the data were not appreciably affected by their presence.

RESULTS AND DISCUSSION

General Description

Oscillations were encountered which were evidently self excited rather than wave excited, since they did not depend on the presence of waves or ripples on the water. The vibration occurred only when the wetted length was small with respect to the beam (at high aspect ratio). For example, during a typical test run with constant load and increasing speed, the hydro-ski started to vibrate in the first mode in bending (with largest displacement at the trailing edge and midway between the pivots) when the aspect ratio of the wetted portion reached about 10. The frequency was slightly higher than the natural frequency in air. As the speed was increased the first mode was succeeded by an interval of irregular vibration which was followed by higher modes. The vibration in many instances was accompanied by a drumming sound which was apparently caused by the rapid succession of impacts of the planing surface with the water surface. At low trims the oscillations appeared gradually and were of small amplitude. At light loads and high trims, the model became airborne during the test run.

A series of frames from a motion picture of the vibrating hydro-ski is shown in figure 6. The camera was located on the starboard side, above and slightly forward of the trailing edge. The ski is moving to the right and the trailing edge is slightly above the center of the picture. The wake, which can be seen to the left of the trailing edge, is composed of approximately square depressions which are surrounded by spray. The frequency of vibration was 50 cycles per second and the camera speed was slightly less than 50 frames per second, the result being that the sequence of photographs shows successive stages in the vibration cycle. The first photograph shows the ski entering the water and photographs 2 to 12 show subsequent stages of the formation of a depression in the water. In photograph 13 the hydro-ski is out of the water. The last three photographs show the start of the formation of another depression.

Vibration Without Trim Motion

By using the arrangement of figure 4, a self-excited vibration was obtained without motion in trim. This vibration occurred under the same conditions of load, trim, speed, and aspect ratio and had about the same frequency as that experienced with the configuration of figure 1. Evidently the vibration of the hydro-ski (fig. 1) and that of the arrangement shown in figure 4 are both examples of a vibration phenomenon which occurs with planing surfaces at high aspect ratios (order of 10). This phenomenon is not explainable on the basis of coupling between trim and rise motions, since it may occur without freedom in trim.

Vibration Boundaries

Figures 7 to 12 show the speed at which the first mode of vibration started for the basic ski and for the various modifications for a load range from 5 to 60 pounds (with the exception of the 0.5-inch-thick ski, for which the load range was from 5 to 40 pounds), speeds up to 80 feet per second, and trims (measured at zero load) from 3° to 25°. The absence of data for any condition of load, speed, and trim within these limits indicates that vibration either did not occur or started so gradually that the starting point was not definable. The scarcity of data at trims below 10° is the result of a tendency for the starting point to be indefinite at low trims. The conditions for which vibration did not occur are indicated in the figures. The speed at which vibration started increased with increase in load and, in general, decreased with increase in trim.

The effects of load and trim on the vibration boundary of the basic configuration are shown in figure 7. In order to facilitate comparison of the modifications, these curves for the basic hydro-ski have been repeated in all subsequent figures as solid lines.

The effects of changes in the shape of the planing surface are presented in figures 8 to 10. Dead rise of 10° caused the vibration boundary to move to higher speeds. (See fig. 8.) An even more favorable effect, however, was a great reduction in the severity of the vibration. Increasing the dead rise to 20° completely eliminated the vibration for the range of speed and load tested. The effect of transverse curvature (fig. 9) was very similar to that of dead rise. The vibration with the 4.86-inch curvature was so feeble that it was practically negligible. The vibration speeds with various types of pointed trailing edges are shown in figure 10. The single point and the two points completely eliminated the vibration for the range of speed and load tested. The vibration boundary was not significantly different with the five-pointed trailing edge than with the basic trailing edge, but the severity of the vibration was much less with the points than without. Because these planing-surface changes limited the wetted aspect ratio, their success is additional evidence that the vibration only occurs with high wetted aspect ratio.

The effects of modifications which alter the mechanical properties of the planing surface are presented in figures 11 and 12. Figure 11 shows the effect of hydro-ski thickness on the vibration boundaries. In general, the behavior of the 0.50-, 0.75-, and 0.94-inch-thick hydro-skis was similar, especially at high loads and trims. The vibration of the 1.25-inch hydro-ski usually started so gradually that the starting point could not be determined. The speed at which vibration started for the 1.50-inch hydro-ski (60 percent thicker than the basic ski) was considerably higher than for the others. The effect of reducing the overhang from 17 inches to 9 inches (fig. 12) was slight, but at 5 inches overhang (a reduction of 70 percent) the vibration was eliminated for the range of speeds and loads investigated.

CONCLUDING REMARKS

A preliminary investigation of vibrations of single planing surfaces has indicated that self-excited vibrations occur with a high aspect ratio (order of 10) of the wetted portion and may occur without a change in trim angle. The oscillations can be decreased in severity or eliminated by the use of planing surfaces which limit the wetted aspect ratio. Dead rise, transverse curvature, and a pointed trailing edge are all effective. A 60-percent increase in the thickness of the hydro-ski caused a definite increase in the speed at which vibration first occurred. A 70-percent decrease in the overhang eliminated the vibration for the ranges of speeds and loads investigated.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., September 1, 1955.

REFERENCES

1. Shoemaker, James M.: Tank Tests of Flat and V-Bottom Planing Surfaces. NACA TN 509, 1934.

2. Truscott, Starr: The Enlarged N.A.C.A. Tank, and Some of Its Work. NACA TM 918, 1939.

TABLE I.- MECHANICAL PROPERTIES OF HYDRO-SKIS

(a) Various thicknesses and 17 inches of overhang

Thickness, t, in.	First mode natural frequency, cps	Static deflection	
		Linear, in./lb (a)	Angular (trim), deg/lb (b)
0.50	23.2	0.0326	0.131
.75	31.1	.0145	.058
[c].94	37.4	.0083	.034
1.25	53.6	.0036	.014
1.50	73.0	.0018	.007

(b) Various amounts of overhang and 0.94 inch thickness

Overhang, l, in.	First mode natural frequency, cps	Static deflection	
		Linear, in./lb (a)	Angular (trim), deg/lb (b)
[c]17	37.4	0.0083	0.034
13	43.3	.0048	.027
9	46.7	.0027	.018
5	47.5	.0012	.010
1	47.8	.0002	.002

[a]Load applied and deflection measured at the trailing edge, perpendicular to the bottom of the hydro-ski.

[b]Load applied at the trailing edge, perpendicular to the bottom of the hydro-ski. Angular deflection (change of trim) measured at the trailing edge.

[c]Basic configuration (figs. 1, 2, and 3(a)).

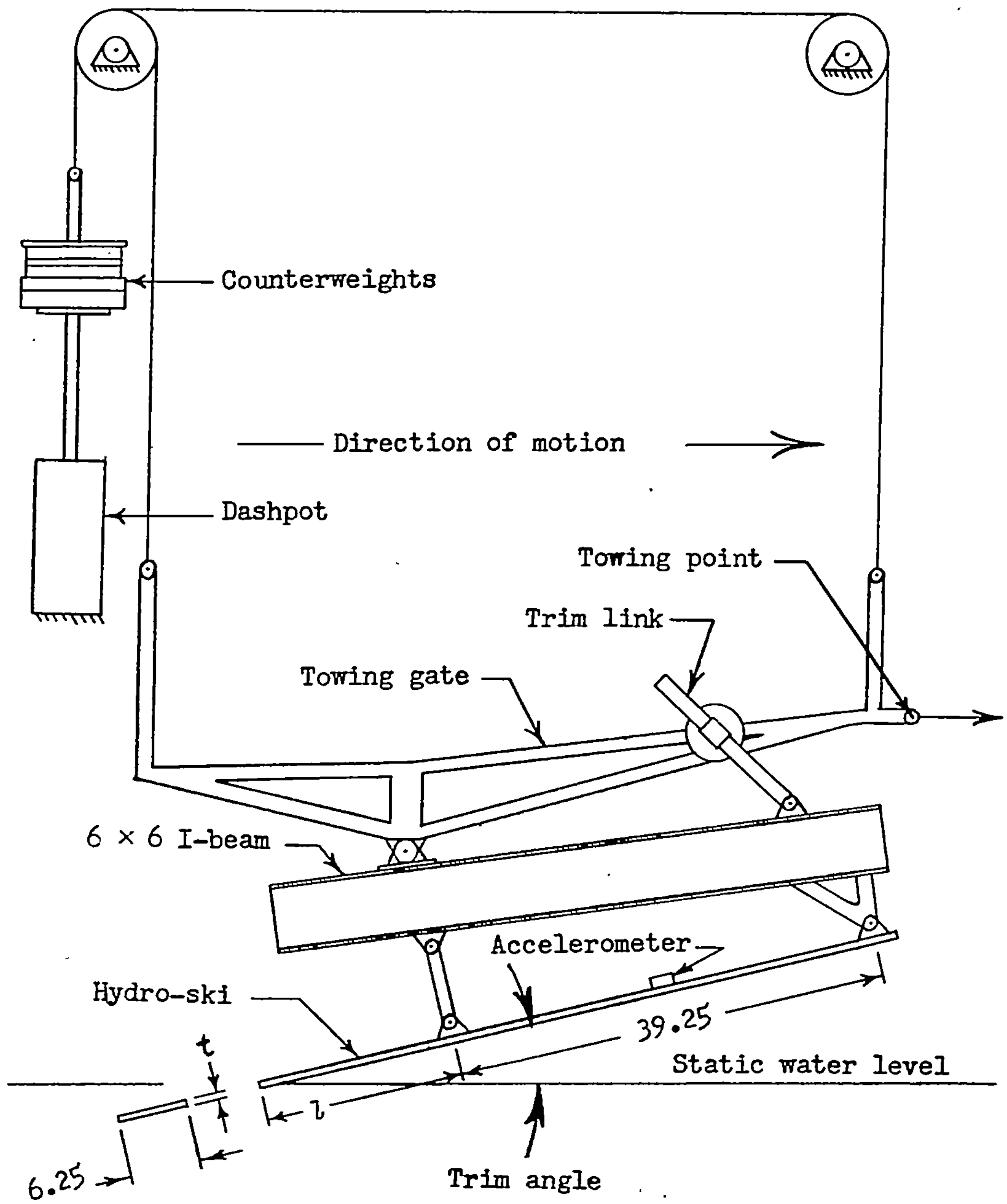

Figure 1.- Schematic diagram of model and apparatus. Dimensions are in inches.

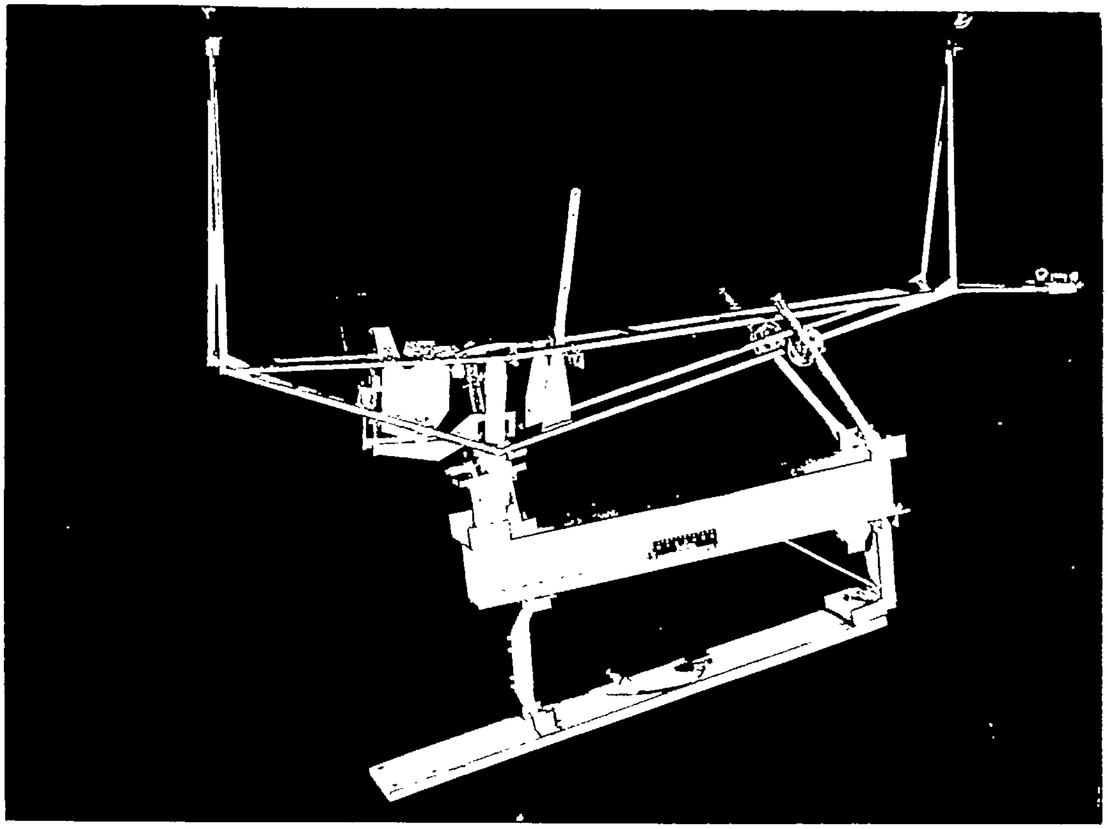

Figure 2.- Model and apparatus. L-90488

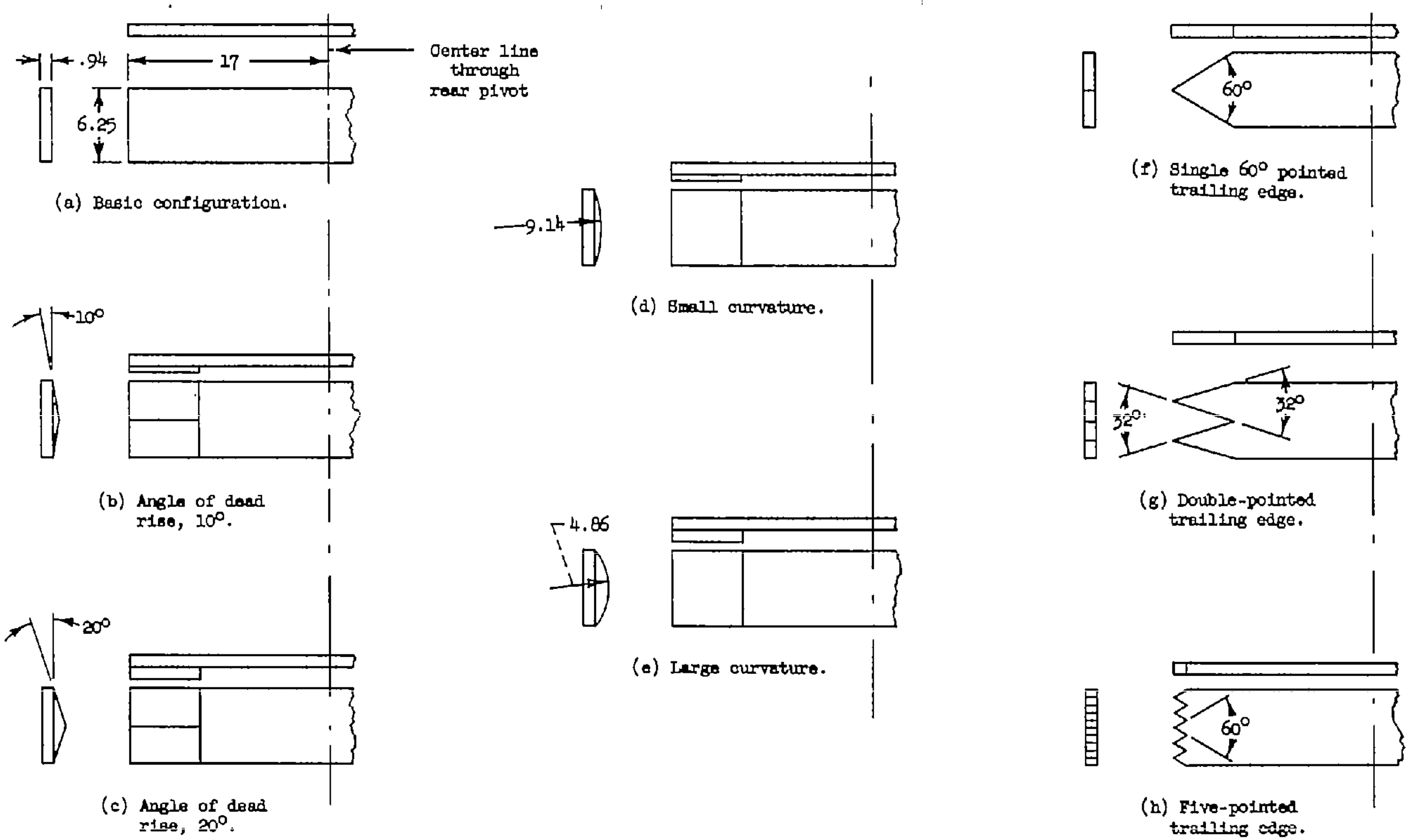

Figure 3.- Planing-surface configurations. Dimensions are in inches.

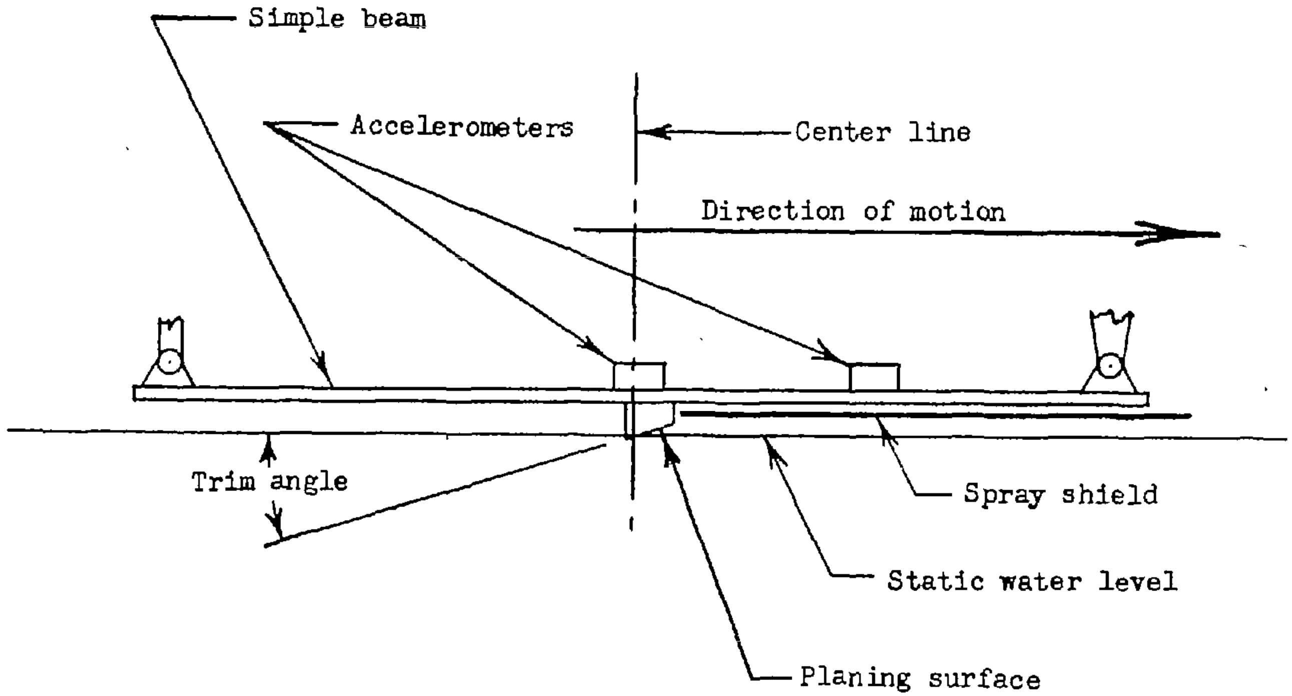

Figure 4.- Arrangement of apparatus with model which permits freedom in rise without motion in trim.

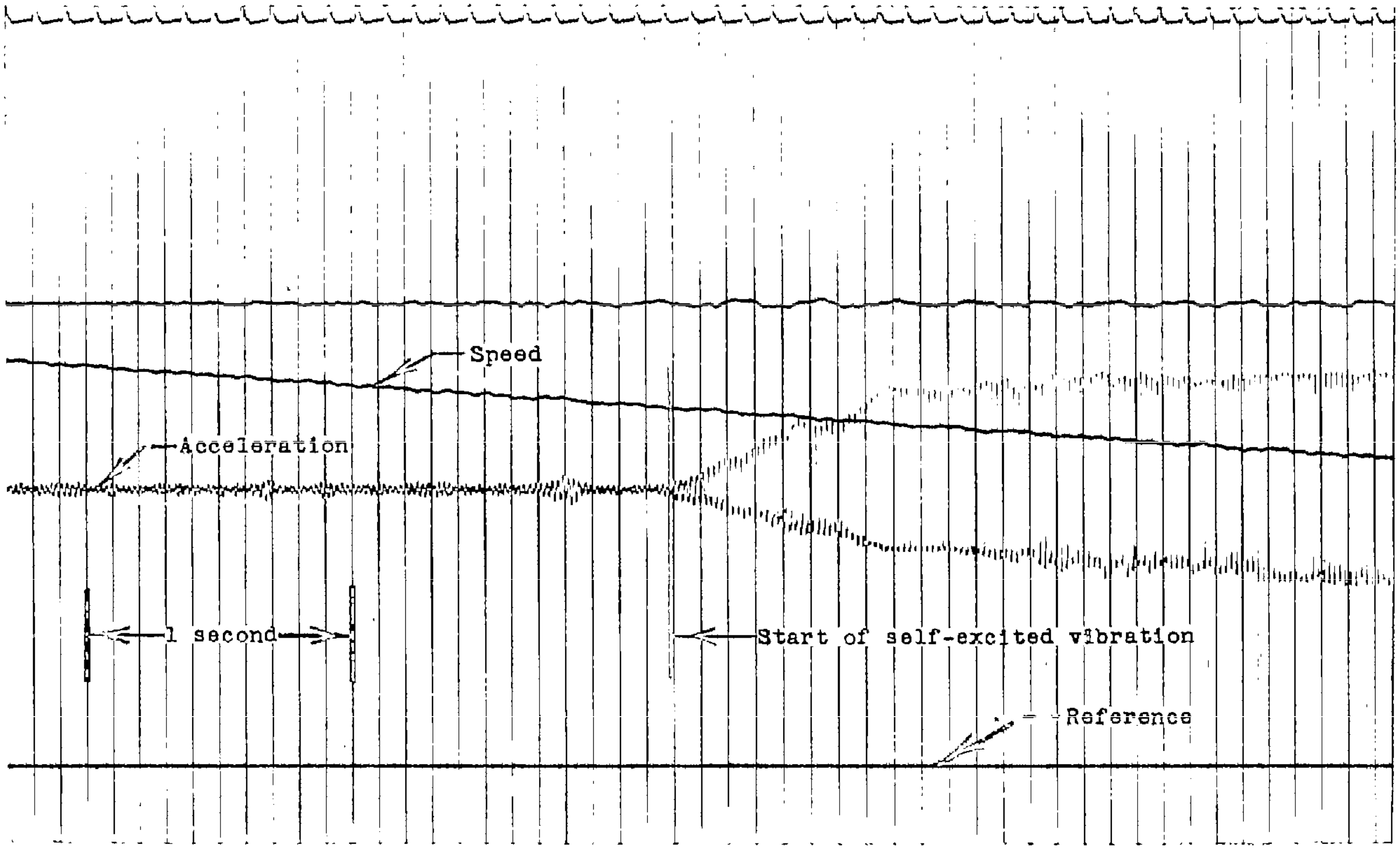

Figure 5.- Part of oscillograph record showing start of vibration.

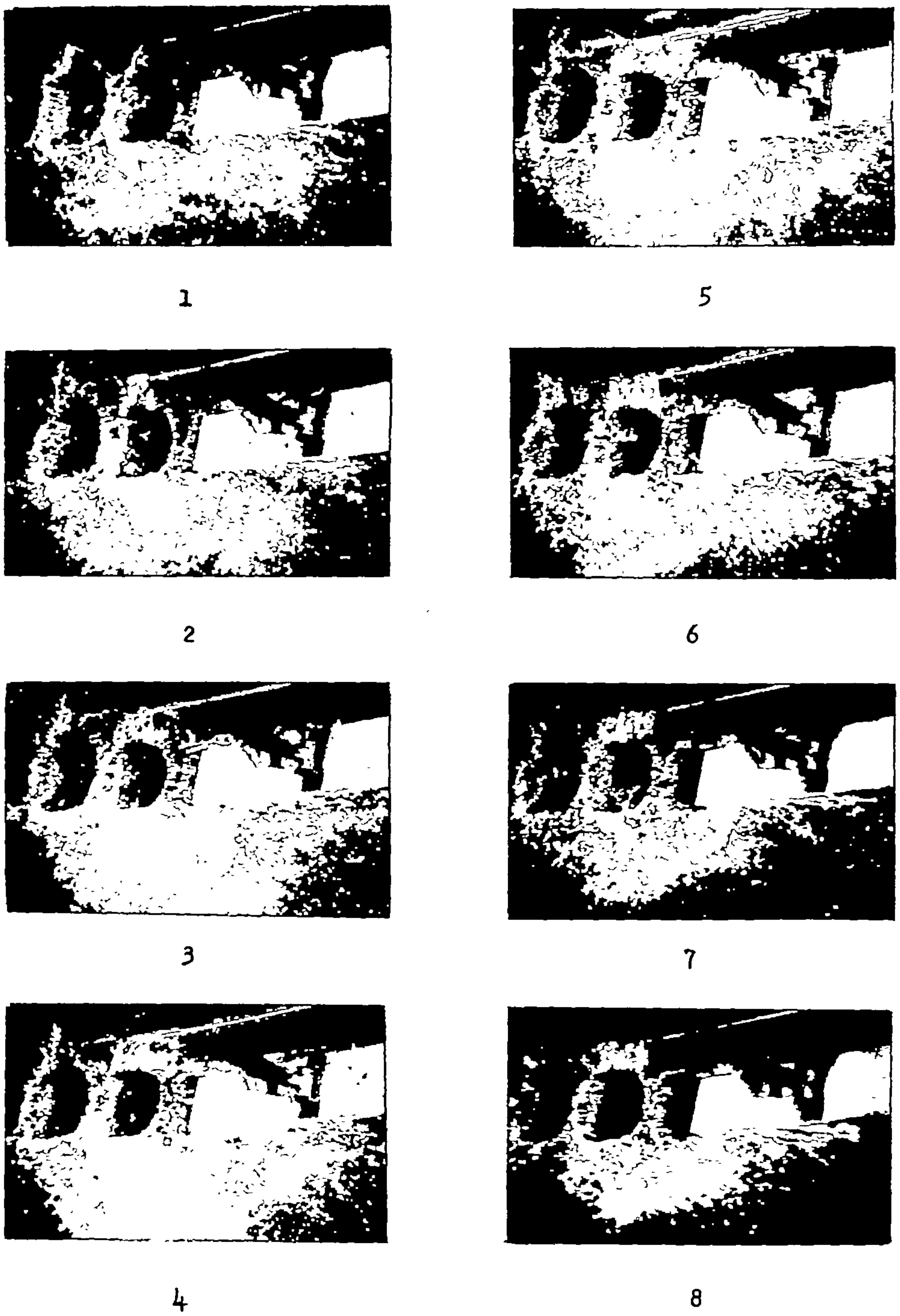

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Figure 6.- Consecutive photographs of the vibrating hydro-ski. Thickness of hydro-ski, 0.94 inch; load, 20 pounds; speed, 45 feet per second; trim, 20°.

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L-90490

Figure 6.- Concluded.

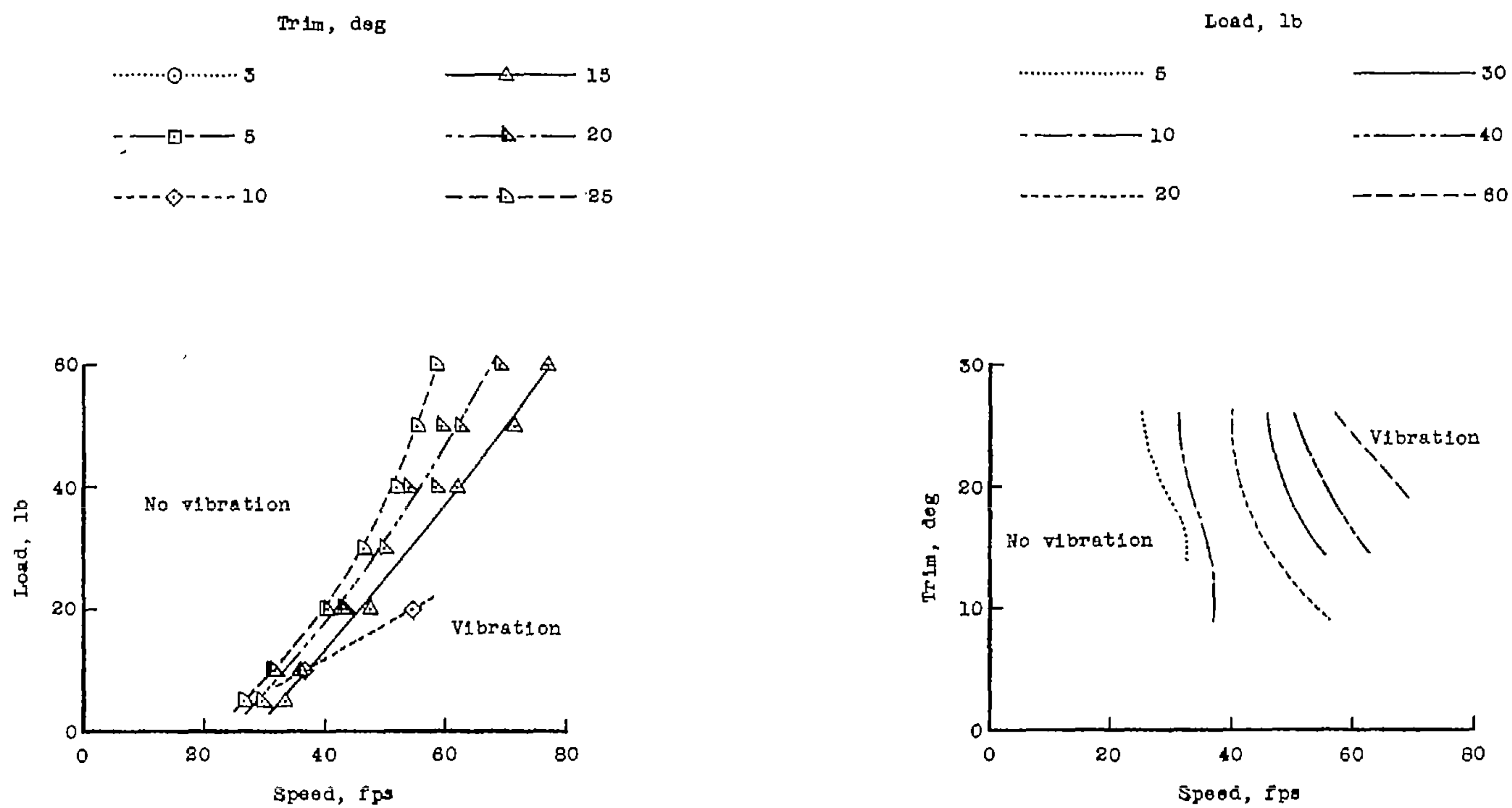


Figure 7.- The effects of load and trim on the speed at which vibration starts for the basic hydro-ski configuration (figs. 1, 2, and 3(a)).

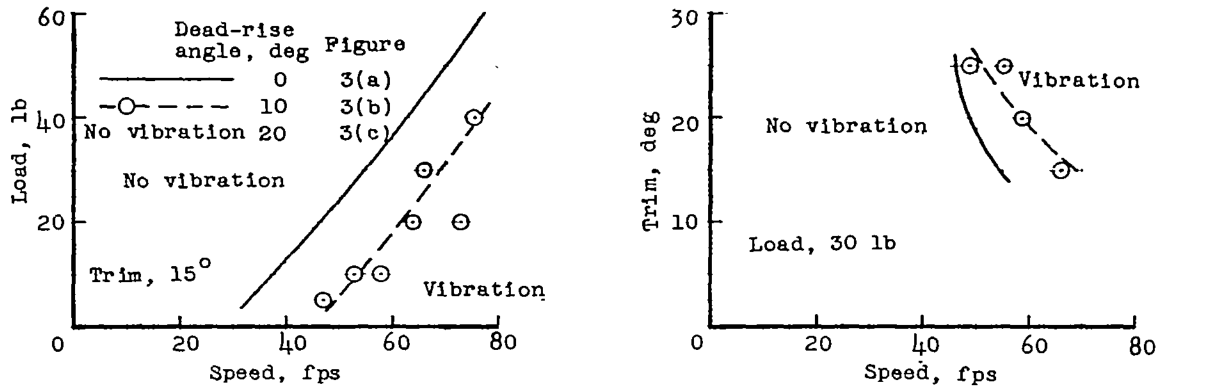


Figure 8.- The effect of dead rise on vibration boundaries.

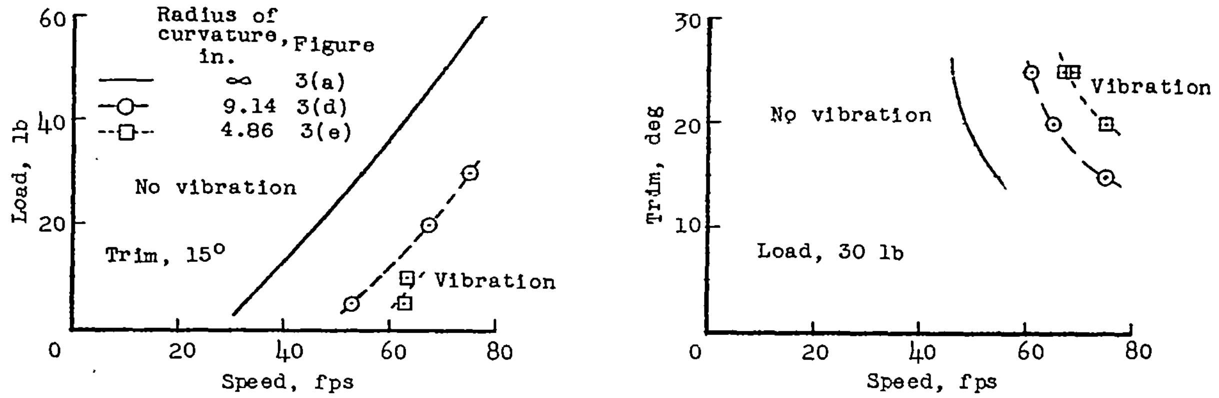


Figure 9.- The effect of transverse curvature on vibration boundaries.

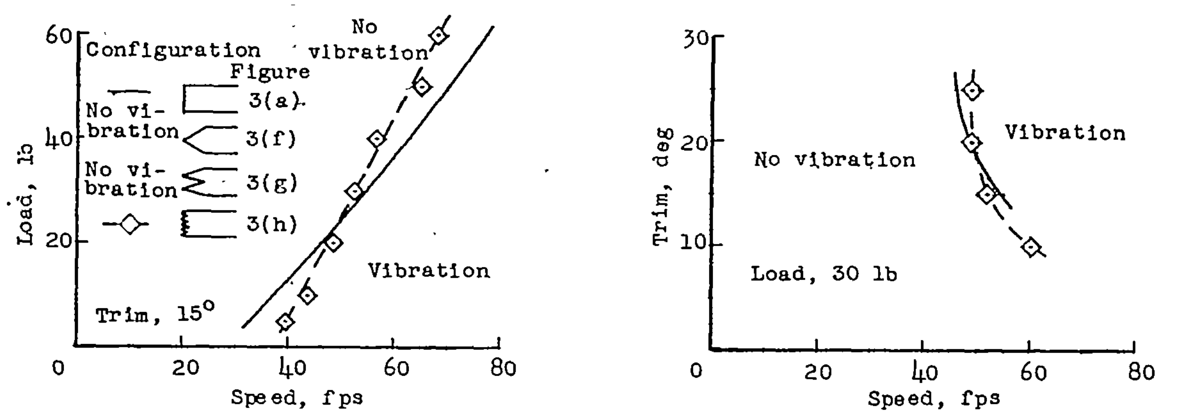
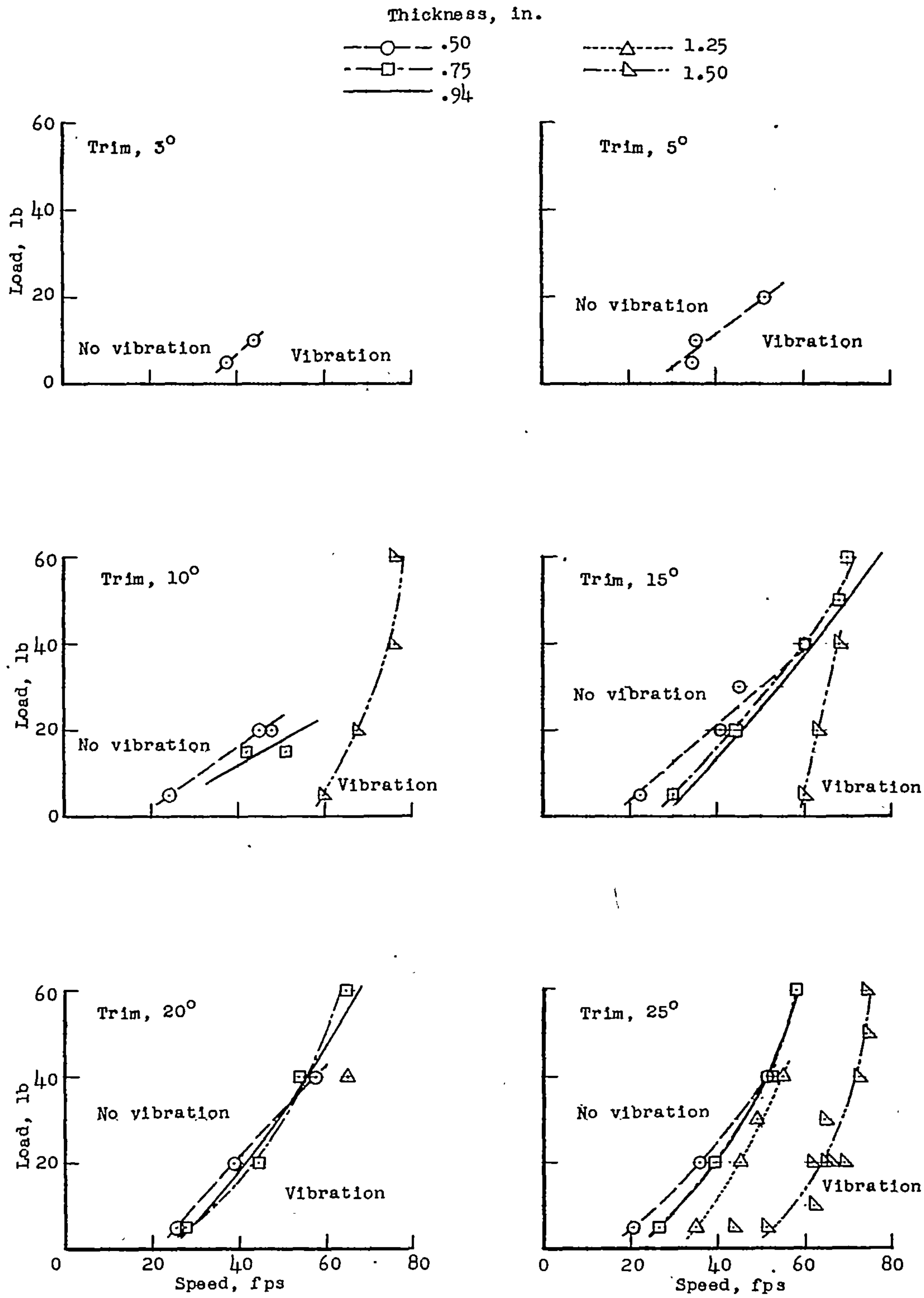
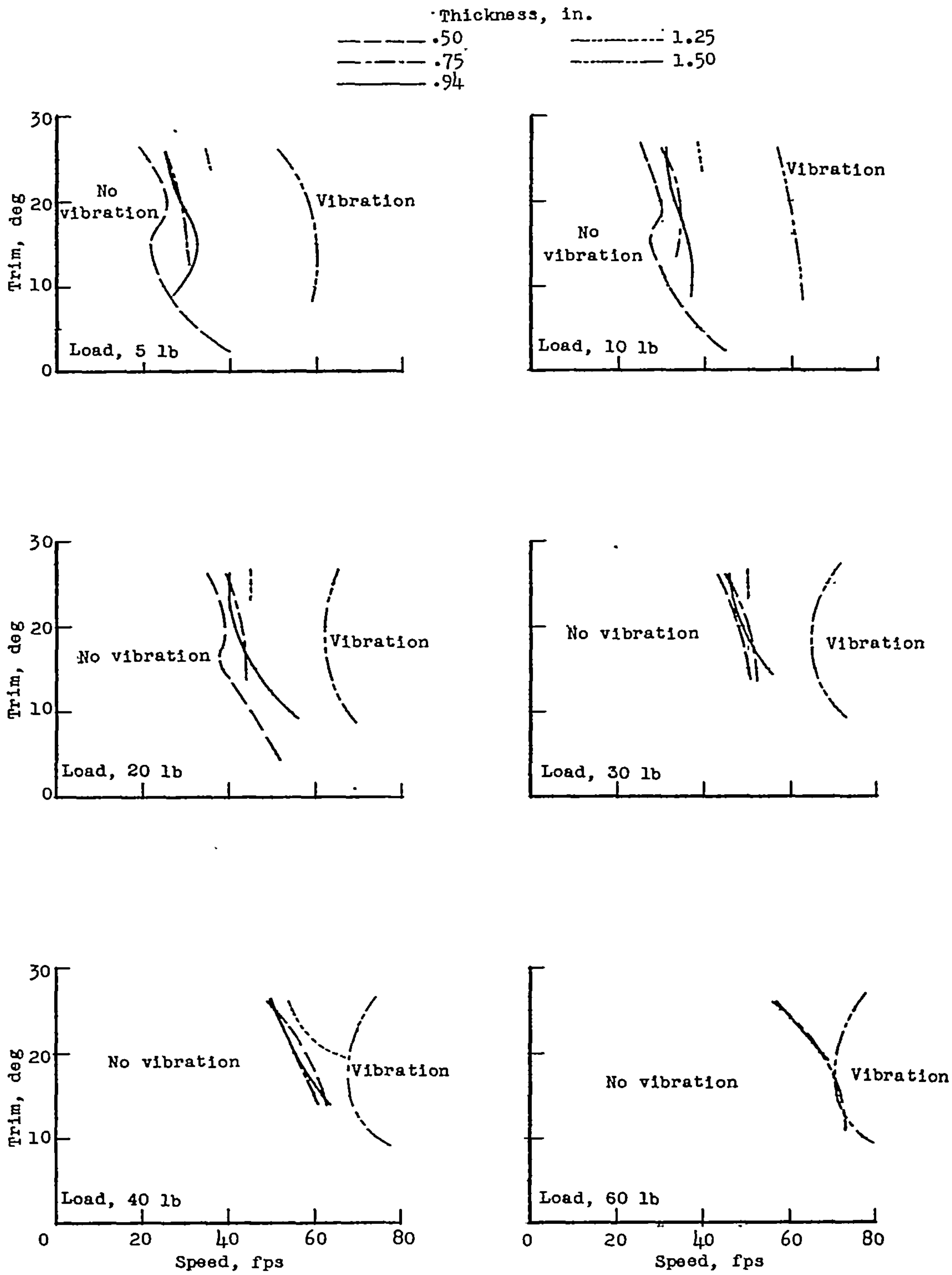


Figure 10.- The effect of pointing the trailing edge on vibration boundaries.



(a) Load against speed.

Figure 11.- The effect of thickness on vibration boundaries.



(b) Trim against speed.

Figure 11.- Concluded.

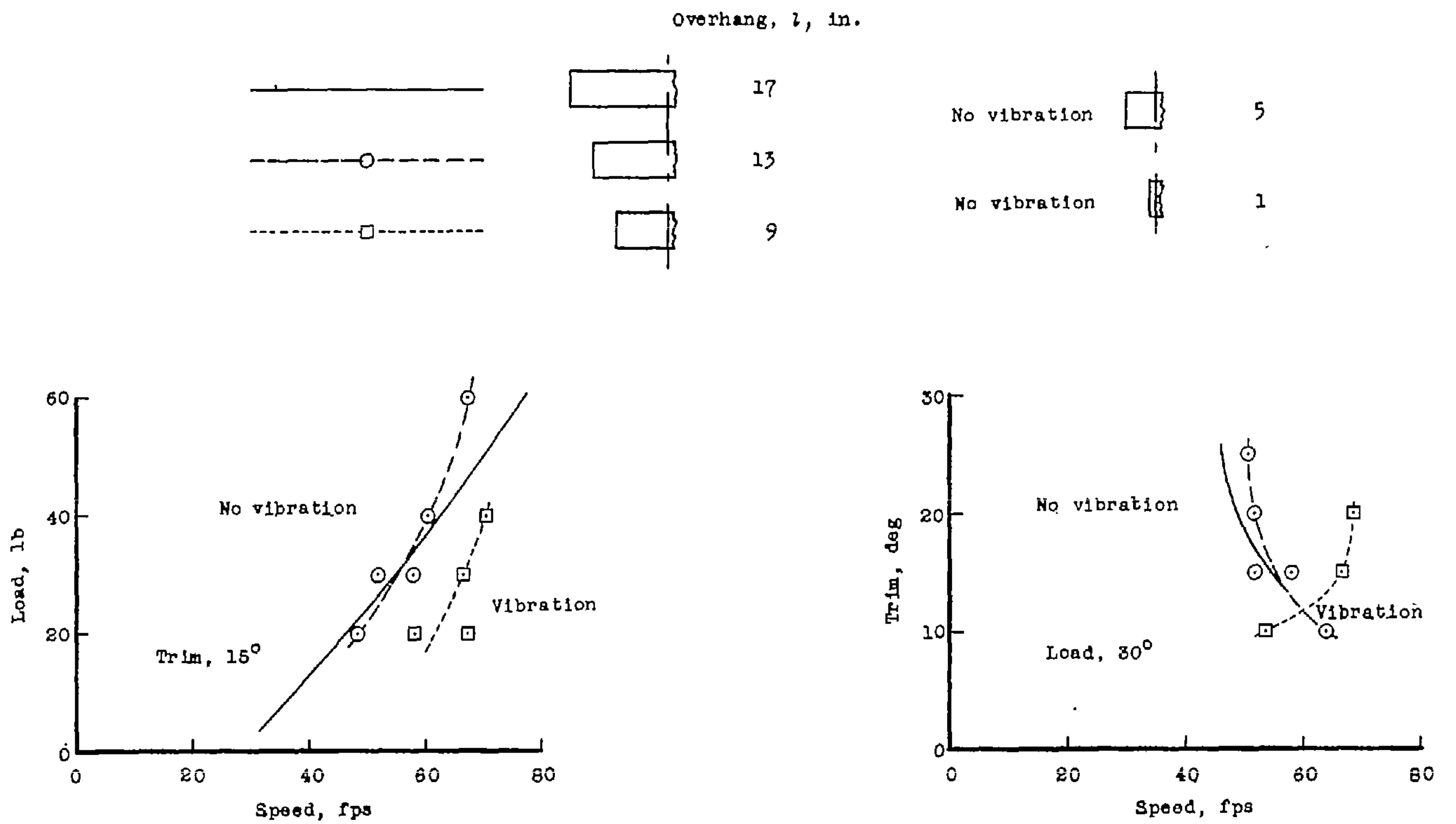


Figure 12.- The effect of overhang on vibration boundaries.

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